QUANTIFICATION OF HYDROCARBON EMISSIONS FROM THE CANADIAN GASOLINE MARKETING DISTRIBUTION SYSTEM

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Petroleum Association for Conservation
of the Canadian Environment
1202 - 275 Slater Street
OTTAWA, Ontario K1P 5H9

Prepared by

Concord Scientific Corporation
TORONTO, Ontario

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hydrocarbon emissions from all marketing sources together with the Statistics Canada throughput for each province are as follows:

	Emissions (tonnes)	Throughput (10^3 m^3)
British Columbia	8,989	3,460
Yukon	63	35
Alberta	8,729	3,482
Northwest Territories	124	37
Saskatchewan	3,507	1,246
Manitoba	3,812	1,191
Ontario	31,244	10,842
Quebec	17,076	6,172
New Brunswick	2,679	811
Nova Scotia	3,285	976
Prince Edward Island	610	143
Newfoundland	2,098	497
Total	82,216	28,892

These emissions are in good agreement with the 1980 emissions reported by EPS (Vena, 1986) when account is taken of throughput differences for the two years. Included in the total emissions are benzene emissions of between 270 and 820 tonnes - a range determined by uncertainty in the benzene content of gasoline (1-3%).

The overall uncertainty in the emissions data calculated in this study is estimated at 50%.

The hydrocarbon emissions from the marketing and distribution system are approximately 0.42% of the total throughput. The contribution of gasoline marketing and distribution to the total Canadian volatile organic compounds (VOC) emissions is small (~ 4%). Most hydrocarbon emissions occur in Ontario (38%) while within the marketing and distribution system, service station losses account for 63% of the total.

INTRODUCTION

1 INTRODUCTION

PACE is committed to gather good technical background data on the amount of hydrocarbon emissions during the marketing of gasoline in Canada. This information will allow PACE members to determine whether hydrocarbon emissions associated with gasoline marketing are significant in the context of total organic emissions from anthropogenic and natural sources. If marketing of gasoline in Canada makes a significant contribution to total organic emissions, then the background information gathered will focus attention on those areas in the marketing chain for regions of the country where emissions rates are highest.

Previous PACE reports have documented emissions at refineries (e.g. Petroleum Refinery Emission Survey for 1978, PACE Report 80-5, and the recently completed update for 1983, PACE Report 85-1) and at service stations (Canadian Service Station Fuel Transfer Emissions, PACE Report 83-3). A notable contribution contained in the latter work was the development of models describing and quantifying the emission processes occurring at service stations. Emissions associated with the remainder of the gasoline distribution system have not previously been assessed.

The objectives of this study were to:

a) identify and quantify the total hydrocarbon emissions in the gasoline marketing and distribution system on a province-by-province basis

b) estimate the benzene emissions from the marketing and distribution system

c) assess the importance of the above hydrocarbon emissions relative to the total national anthropogenic volatile organic compounds (VOC) emissions.

The work described in this report was therefore undertaken to quantify the hydrocarbon emissions in the Canadian marketing distribution system for the calendar year 1983.

Emissions resulting from the following activities were therefore quantified for each province and territory:

- storage and loading losses at marketing terminals and bulk plants
- losses in transit
- delivery, storage, and vehicle refuelling losses at service stations.

The last item involves an update of the emissions reported in PACE Report 83-3 referred to above, and makes use of the models developed in that work. Losses occurring at refineries have been treated separately, in the Petroleum Refinery Emission Survey for 1983.

1.1 Background

The group of chemical compounds known as volatile organic compounds (VOC) are of concern because of their participation in chemical reactions in the atmosphere leading to the production of oxidants. Ozone is generally the most important of the oxidants, and has long been recognized as one of the major pollutant species in photochemical smog. Recent studies funded by the federal government have focussed on the oxidants problem in certain areas of Canada.

For example, Vancouver is believed to experience higher ozone levels than any other city in the world at similar latitude. It has been demonstrated (CSC, 1982; 1985) that these high ozone levels are attributable to local precursor emissions only, with no significant contribution from transported pollutants.

High ozone levels are frequently experienced in the region stretching through Southern Ontario from the U.S. border, and up to Montreal and Quebec City. Here the situation is complicated by transport into the region of ozone (and/or its precursors) produced south of the border, in addition to that resulting from local precursor emissions (CSC, 1983; Kelly et al., 1986).

The detrimental effects of oxidants on human health, crops, forests and materials are documented. In addition, oxidants are implicated in the phenomenon of acid rain, since they participate in the reactions which convert emitted oxides of nitrogen and sulphur to nitric and sulphuric acids respectively.

As a responsible group, PACE members therefore desire to have at their disposal the best quality information available regarding emissions resulting from their activities. This will allow discussions and resultant decisions to be made on the basis of relevant data.

It is important to note that volatile organic compounds differ widely in their chemical reactivity in the atmosphere. From the point of view of pollution control the product of reactivity and mass emitted is therefore more important than mass alone. The issue of hydrocarbon reactivity is not addressed in this report.

1.2 Report Organization

The basis for the calculation of emissions is summarised in Chapter 2 of this report, and the emissions data are tabulated and summarised in Chapter 3. Conclusions and recommendations are presented in Chapter 4,

and pertinent references are listed in Chapter 5. The assumptions required in the calculations, and the uncertainties associated with the data are discussed in Appendix I, and a copy of the questionnaire used in data collection is included as Appendix II.

EMISSION CALCULATION PROCEDURES

2 EMISSION CALCULATION PROCEDURES

The distribution chain for gasoline is summarised in Figure 2.1. Loss to the atmosphere may occur during storage and handling at all points in this chain. In this report estimates have been made of hydrocarbon emissions associated with:

- storage at marketing terminals
- handling at marketing terminals
- storage at bulk plants
- handling at bulk plants
- storage at service stations
- vehicle refuelling at service stations
- losses in transit between the various points in the chain.

Emissions have been calculated for each province and territory. No assignment of these emissions to chemical or reactivity class has been made, except that the emissions of benzene as a distinct compound have been quantified.

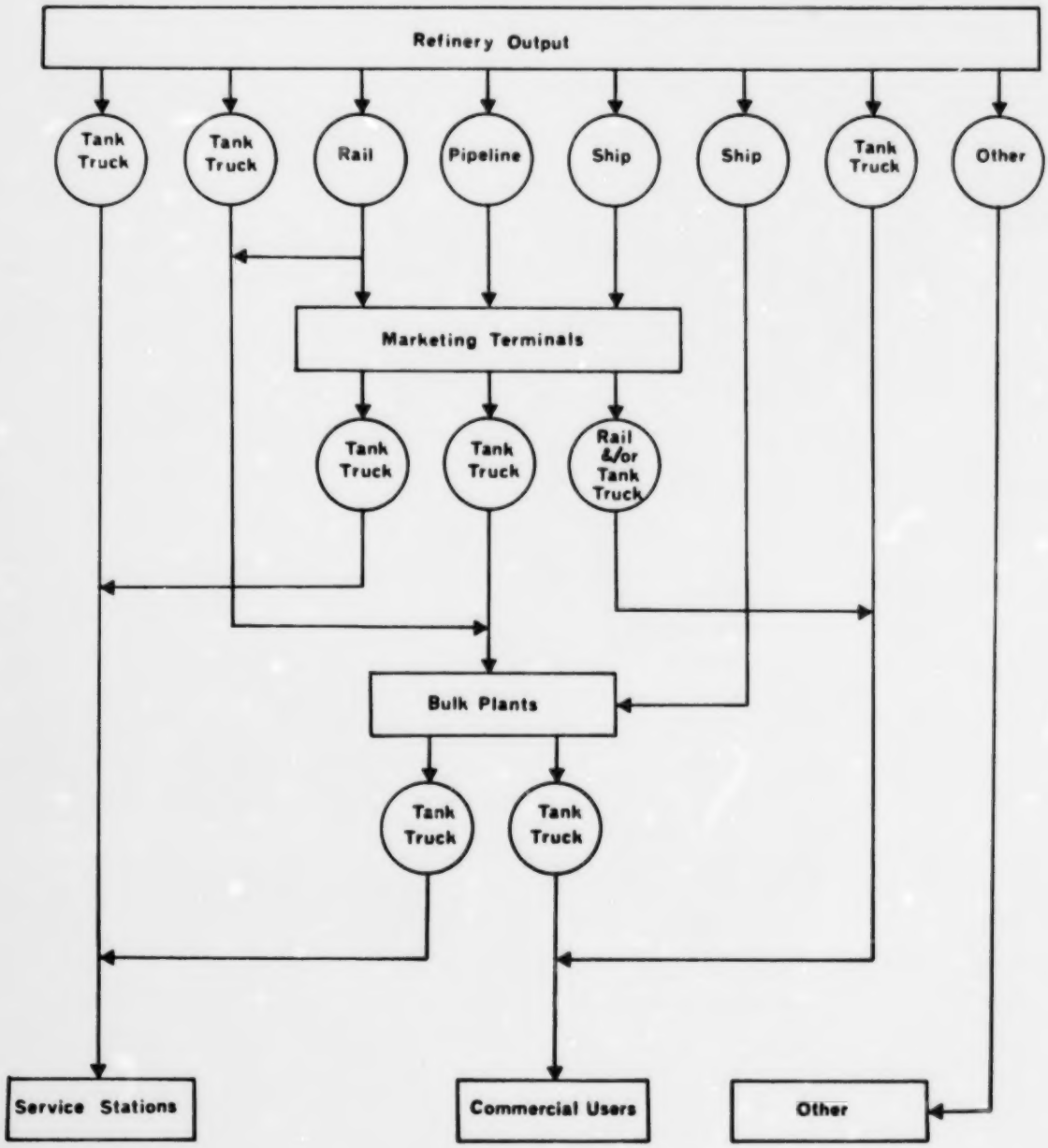
The basis for the emission calculations and the methods used to retrieve the required data are described separately below.

2.1 Emission Rate Equations

Emission rate equations and procedures related to gasoline marketing (and a very wide range of other processes) are summarized in the US Environmental Protection Agency publication commonly known as AP-42 (US EPA, 1977; and subsequent supplements). The sections in the EPA publication covering petroleum liquids are generally based on work carried out under the auspices of the American Petroleum Institute (API), and reported in API bulletins. In some cases updated, equations have been developed (e.g. API, 1983; Laverman, 1984). These are referred to where appropriate. However, the US EPA compilation (AP-42)

FIGURE 2.1

Gasoline Marketing Distribution System



is used as the general reference. Note that the equations are mainly expressed in US units. It is also important to note that these equations represent empirical correlations of observed loss rates, and are therefore not derivable from first principles.

2.1.1 Storage losses

Gasoline is stored in tanks, which are generally of the fixed or floating roof type. Smaller horizontal tanks are also in service, and are treated as fixed roof tanks.

Losses are greatest from the fixed roof type of tank, since a head space is available, unless the tank is completely full, which will contain a substantial amount of vapour. These vapours can then be expelled to the atmosphere through a breathing mechanism driven by day/night thermal cycling, and by barometric pressure changes.

As the name implies, floating roof tanks incorporate a roof which floats on the stored liquid, thus eliminating the head space. They may or may not include a fixed roof as well. The major loss mechanism during storage for external floating roof tanks is evaporation assisted by wind flow across the top of the tank. This mechanism is essentially eliminated by the extra roof in internal floating roof tanks. It is clear that the nature and condition of the seals at the roof edge are very important.

Formulae have been given by the US EPA (1981) for calculating losses from storage tanks. They are

Fixed roof: $$L_B = 2.26 \times 10^{-2}\, M\left(\frac{P}{14.7-P}\right)^{0.68} D^{1.73}\, H^{0.51}\, \Delta T^{0.50}\, F_p\, C\, K_C$$

Floating roof: $$L_S = K_S\, V^N\, P^*\, D\, M_v\, K_C\, E_F$$

where L_S, L_B = standing storage loss (lb/year)

M, M_v = molecular weight of the vapour (lb/lb mol)

P = vapour pressure (psia)

P^* = vapour pressure function

$$= \frac{P/P_a}{[1 + (1 - P/P_a)^{0.5}]^2}$$

P_a = atmospheric pressure (psia)

D = tank diameter (ft)

H = average vapour space height (ft)

V = wind speed (mph)

ΔT = average ambient diurnal temperature change (°F)

F_p, C, K_c, K_s, E_F, N = factors allowing for, among other things, paint colour, type of product, adjustment for small diameter tanks, and the nature and condition of the seals (tabulated by US EPA, 1981). These factors are mainly dimensionless.

Additional terms may be included to allow for losses at deck fittings and seams (API, 1983; Laverman, 1984). These terms are not listed here, because as described in the next section, the appropriate data to allow their calculation could not be retrieved.

Other tank types are in use, e.g., those employing a flexible membrane to provide a variable volume vapour space. Formulae have also been given for such tanks (US EPA, 1977), but there are currently none in service in Canada (Hailes, 1985).

2.1.2 Handling emissions

Under this heading are emissions associated with:

- filling and emptying the storage tanks

- filling the transport vehicle, which may be a truck, a railway tank car or a ship

Several mechanisms exist for emission from storage tanks during filling and emptying. For example, filling of a fixed roof tank causes a reduction in the space available for vapour, and thus its expulsion. During emptying of a floating roof tank, material which remains clinging to the tank walls as the floating roof drops is able to escape when it evaporates. Formulae for calculating these working emissions are (US EPA, 1981):

Fixed roof: $L_w = 2.40 \times 10^{-2} MPK_N K_C$

Floating roof: $L_w = 0.943\ QC\ W_L/D$

where L_w = the loss

Q = the average throughput (bbl/yr)

M = Molecular weight of the vapour (lb/lb mol)

P = vapour pressure (psia)

D = tank diameter (ft)

W_L = the liquid density (lb/gal)

K_N, K_C, and C = factors relating to the turnover, the nature of the liquid and its cling to the walls of the tank respectively (tabulated in US EPA, 1981). These are dimensionless quantities.

Note that L_w is expressed as (lb/1000 gal throughput) for fixed roof tanks, and as (lb/year) for floating roof tanks.

For internal floating roof tanks, columns are generally present to support the external roof. These necessarily penetrate the floating roof, and their contribution to the loss, L_w, may be accounted for by the multiplicative factor (API, 1983)

$$1 + (N_c F_c / D)$$

where N_c = number of columns
F_c = effective column diameter (ft)
D = tank diameter (ft).

Trucks, rail cars and ships may be loaded using the splash method or the submerged method. In addition, trucks and rail cars may be loaded through an inlet located at the bottom of the tank. The splash method leads to the highest emission levels.

Formulae have been given by the U.S EPA (1979) for calculation of emissions relating to loading of trucks, rail cars and ships, and updated procedures for marine vessel loading have also been described by the American Petroleum Institute (API, 1981).

It should be noted that these emissions depend critically on the previous history of the container used, that is on the nature and amount of the vapour (if any) remaining in it. It is general to distinguish the following conditions:

- clean tank
- normal dedicated service tank (uncleaned)
- average tank condition
- ballasted tanks (ship only).

Of critical importance is the amount of vapour control practised during the loading operations. Some control is currently employed in Canada (top loading with extended fill pipes, bottom loading), but closed cycle vapour capture is not practised.

Note that breathing losses also occur while the cargo is in transit. These are equivalent to the storage losses experienced by fixed roof tanks and must also be calculated. They are not, in general, simply

functions of the transit time, but rather are driven by temperature changes of the cargo which change the vapour pressure.

The emissions for loading of gasoline into tank trucks and rail tanks cars are given as (US EPA, 1978)

$$L_L = 12.46 \text{ SPM/T}$$

where L_L = loading loss (lb/1000 gal loaded)
M = molecular weight of vapour (lb/lb mol.)
P = true vapour pressure of the liquid (psia)
T = bulk temperature of the liquid being loaded (°R)
S = saturation factor

The saturation factor relates to the extent of saturation of the vapours expelled during loading, and is a function of the loading method. Values of S are given in Table 2.1 for loading of tank trucks and railway tank cars.

For loading of marine vessels it is recommended (US EPA, 1978) that emissions be calculated by

$$L = EF.V$$

where L = emissions (lb)
EF = emission factor (lb/1000 gal loaded)
V = volume of fuel loaded (1000 gal).

Emission factors are listed in Table 2.2. The API (1983) equation is similar to the above, but is generalised for a variety of petroleum products. A relatively limited amount of gasoline is carried by ship in Canada, except in coastal areas.

TABLE 2.1

Values of the saturation factor, S, for tank truck and tank car loading

Mode of Operation	S
Submerged loading, clean tank	0.50
Splash loading, clean tank	1.45
Submerged loading, dedicated service	0.60
Splash loading, dedicated service	1.45
Submerged loading, dedicated vapour balance service	1.00

TABLE 2.2

Hydrocarbon emission factors for gasoline loading of marine vessels

Vessel tank condition	Ships		Ocean Barges		Barges	
	Range	Average	Range	Average	Range	Average
Cleaned and vapor free						
lb/10^3 gal transferred	0 to 2.3	1.0	0 to 3	1.3	a	1.2
kg/10^3 liter transferred	0 to 0.28	0.12	0 to 0.36	0.16		0.14
Ballasted						
lb/10^3 gal transferred	0.4 to 3	1.6	0.5 to 3	2.1	b	b
kg/10^3 liter transferred	0.05 to 0.36	0.19	0.06 to 0.36	0.25		
Uncleaned - dedicated service						
lb/10^3 gal transferred	0.4 to 4	2.4	0.5 to 5	3.3	1.4 to 9	4.0
kg/10^3 liter transferred	0.05 to 0.48	0.29	0.06 to 0.60	0.40	0.17 to 1.08	0.48
Average cargo tank condition						
lb/10^3 gal transferred	a	1.4	a	a	a	4.0
kg/10^3 liter transferred		0.17				0.48

[a] These values are not available.

[b] Barges are not normally ballasted.

From US EPA (1981).

Breathing losses in transit may be estimated by (US EPA, 1978)

$$L_T = 0.1\ PW$$

where L_T = transit breathing loss (lb/week. 1000 gal transported)
P = true vapour pressure of the liquid (psia)
W = density of the condensed vapour (lb/gal)

2.1.3 Service station emissions

Hydrocarbon emissions at service stations are associated with three activities:

- storage tank refilling
- storage
- vehicle tank refilling

These emissions have been discussed in detail in PACE Report 83-3 (Nichols, 1983). It was concluded that service station storage losses are essentially negligible. This is because the storage tanks are underground, and the large thermal mass eliminates the diurnal temperature cycling which leads to the breathing losses experienced by above-ground tanks. Another potential loss mechanism, aspiration of vapour by wind blowing across the vent pipe, was also shown to be unimportant.

In contrast with the equations presented in the previous Section, the equations relating to service station emissions are derived from a fundamental understanding of the processes involved. Details of the derivations are given by Nichols (1983).

Tank loading losses depend on whether the loading is submerged (by drop tube) or of the splash type. For submerged loading the loss is given (in grams per gallon loaded) by (Nichols, 1983)

$$L_D = \frac{9461\ P_H\ \bar{S}}{T_I(172.5-M_H)}\ (6.95 - \frac{120}{M_H})$$

where M_H = condensate molecular weight (lb/lb. mol)
P_H = fuel vapour pressure (psia)
$\bar{S}$ = average saturation of the emitted vapour (dimensionless)
T_I = initial underground temperature (°R)

It should be noted that Nichols (1983) has used Imperial gallons, whereas the US EPA used US gallons.

Formulae and tables of $\bar{S}$ were also given. It is a function of the amount of fuel delivered and the volume of the initial vapour space.

Splash loading losses, L_S (grams per gallon loaded), are related to equivalent drop tube loading losses by

$$L_S = L_D[1 + F_s\ \frac{V_{GI}}{V_D}\ (V/L - 1)]$$

where F_S = saturation fraction in the vapour space (dimensionless)
V_{GI} = initial vapour space volume (gal)
V_D = delivered volume (gal)
V/L = vapour to liquid ratio (dimensionless)

This equation only applies when the saturated vapour volume is less than the vent space volume. An equation was also given which allows calculation of emissions when this inequality does not hold, but the latter case was felt to be relatively uncommon (Nichols, 1983).

Vehicle refuelling emissions result from the displacement of fuel vapour from the vehicle fuel tank by the incoming liquid fuel. The situation is complicated by the fact that the temperature of the vapour

and the fuel initially in the vehicle tanks is not the same as the temperature of the delivered fuel. The final conditions depend strongly on how much fuel was initially in the tank and how much was actually delivered.

Nichols (1983) has developed a model which incorporates these considerations. The refuelling emissions are expressed as (in grams emitted per gallon of fuel dispensed)

$$L_V = \frac{9461\ P_{HD}}{T_D(172.5 - M_D)} (6.95 - \frac{120}{M_D}) \frac{T_D}{T_I} (\frac{P-P_{HI}}{P-P_{HD}})$$

where P_{HD} = true vapour pressure of the dispensed fuel (psia)
P_{HI} = initial fuel vapour pressure (psia)
T_D = dispensed fuel temperature (°R)
T_I = vehicle fuel tank temperature (°R)
P = ambient pressure (psia)
M_D = molecular weight of the dispensed fuel (lb/lb. mol).

The equations developed by Nichols (1983) represent a significant improvement over the previously available correlations.

Gasoline spilled in the course of vehicle refuelling also represents a loss to the atmosphere. This mechanism was not treated by Nichols (1983). These losses are estimated here by using the emission factor of 0.084 kg per 10^3 litre gasoline sold (EPS, 1983).

2.2 Benzene Emission Estimates

Separate quantification of benzene emissions has been carried out. It is present as a component of gasoline to the extent of about a percent unless specifically removed. If gasoline were an ideal solution, Raoult's Law would apply, i.e.

$$P_B = \chi_B P_B^\circ$$

where P_B = vapour pressure of benzene above gasoline (psia)
P_B° = vapour pressure of pure benzene (psia)
χ_B = mole fraction of benzene in gasoline (dimensionless)

Because of departure from ideality, the benzene concentration in the vapour must be determined using a distribution coefficient, K_i, rather than χ_B. Values of K_i were obtained from the graphs and charts given by Nichols (1983).

2.3 Data Collection Procedures

Equations and procedures were presented in the previous sections, which permit calculation of the emissions of hydrocarbons during the marketing of gasoline. Emissions of benzene as a specific component are also calculated.

Rigorous application of these procedures to obtain the best possible estimates of emissions requires a substantial amount of input data. The data fall into the following categories:

- Installation specific data (e.g. tank type, size, construction method).
- Product related data (e.g. type of gasoline, throughput, vapour pressure).
- Climatological data (e.g. ambient and underground temperatures).

The complete data requirements are listed in Table 2.3.

Questionnaires were designed to retrieve the required data from the owners and/or operators of the relevant installations. For bulk plants and marketing terminals the data were requested on a tank by tank basis. The data requrements were simplified by omitting requests for

TABLE 2.3

Data Requirements for Calculation of Hydrocarbon and Benzene Emissions

Installation Specific

- Tank type
- Capacity
- Dimensions
- Paint colour
- Internal condition
- Vapour control methods
- Seal type and condition
- Construction method
- Deck fittings
- Loading method (to transfer vehicle)

Product Related

- Type of gasoline
- Throughput
- Vapour pressure
- Molecular weight
- Liquid density
- Benzene content
- Average delivery to service station
- Average tank contents at delivery

Climatological

- Monthly average air temperature
- Monthly average underground temperature
- Average diurnal temperature change
- Average atmospheric pressure
- Monthly average wind speed.

details of tank construction, fittings, seals and internal condition, since this information was not generally available and would have required a complete tank survey. For service stations, because of the larger numbers involved, the installations were grouped by throughput category, and composite data were requested

The assumptions necessitated by the limitations to the data, and the estimated uncertainties in the emission rates, are discussed in Appendix I.

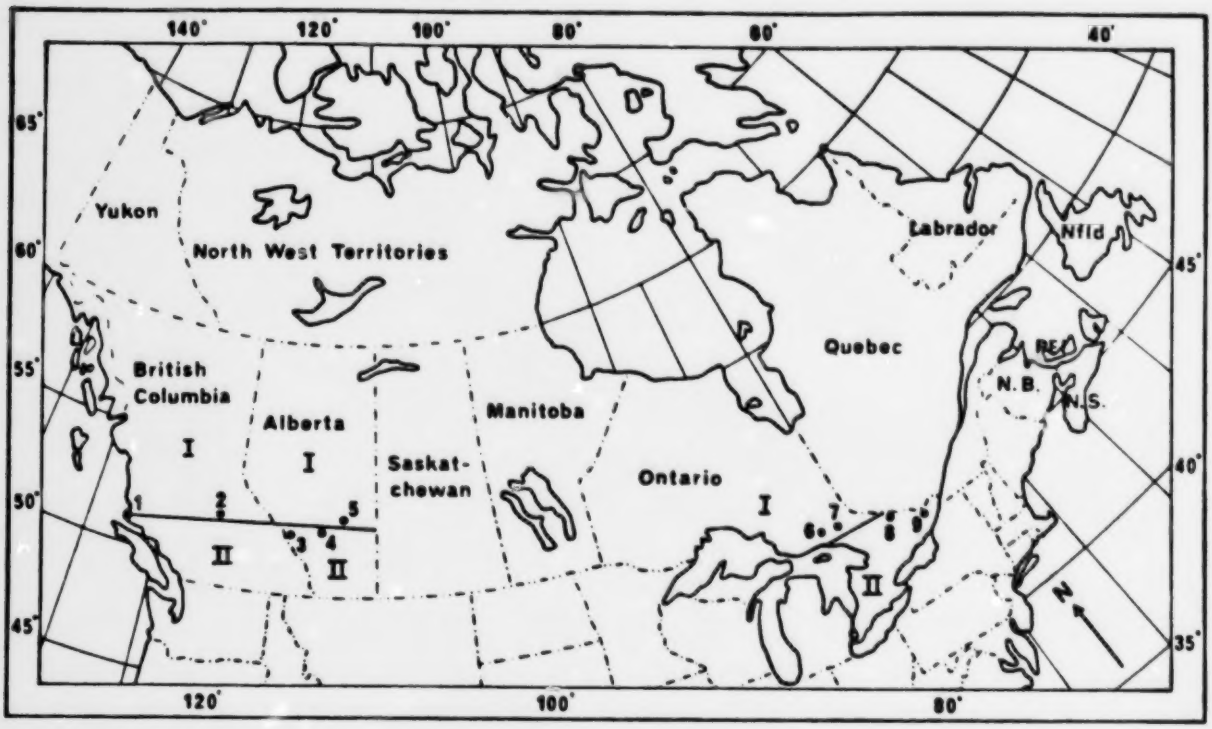
A copy of the final questionnaire is included as Appendix II to this report.

Climatological data requirements were met by reference to the Canadian Climate Normals published by the Atmospheric Environment Service of Environment Canada.

The data were collected with spatial resolution to the provincial level. However, because of relatively large temperature changes across the populated part of the province, British Columbia, Alberta, Ontario and Quebec were each divided into two regions for data collection and calculation. The division is indicated in Figure 2.2.

FIGURE 2.2

Identification of Geographic Regions



KEY

1. Cape Caution
2. 100 Mile House
3. Banff
4. Drumheller
5. Hanna
6. Sudbury
7. North Bay
8. Deep River
9. Ottawa

EMISSIONS DATA

3 EMISSIONS DATA

Hydrocarbon emissions were calculated using the procedures and data described in the previous section. The calculations were performed on a very detailed basis, e.g. tank by tank, and month by month. Thus, a large amount of data was collected, and numerous calculations were required. The individual calculations are not included in this report. Instead, summary results are presented separately below for marketing terminals and bulk plants, and for service stations. Benzene emissions are also reported separately.

3.1 Marketing Terminals and Bulk Plants

The types of tanks found at marketing terminals and bulk plants are essentially identical. The two types of facility are therefore treated together.

Data for marketing terminals and bulk plants were provided by the eight major oil companies. According to the data retrieved in this study, these companies supply 90% of the gasoline marketed in Canada. They are identified in this report by the code numbers one to eight.

The total number of tanks for each of the companies (i.e. total of marketing terminals and bulk plants) is given in Table 3.1. These numbers were taken directly from the completed questionnaires. Table 3.2 gives the throughput, also as reported by the responding companies. It should be noted that this throughput is the sum of the throughputs for marketing terminals and bulk plants. A certain fraction of all gasoline passes through both marketing terminals and bulk plants, and is therefore counted twice. The total throughput in Table 3.2 should therefore not be compared with figures published elsewhere (e.g. Statistics Canada, 57-003).

Storage related emissions of hydrocarbons are listed in Table 3.3, while Table 3.4 gives the sum of loading losses and losses in transit

TABLE 3.1

Number of Storage Tanks for Responding Companies (1983)

COMPANY	B.C.	YUK.	ALTA.	NWT.	SASK.	MAN.	ONT.	QUE.	N.B.	N.S.	P.E.I.	NFLD	TOTAL
01	-	-	-	-	-	-	51	9	-	-	-	-	60
02	60	-	119	-	75	51	189	62	21	33	4	3	617
03	11	-	17	-	14	5	34	-	-	-	-	-	81
04	20	-	16	-	8	4	249	33	14	17	4	-	365
05	21	-	12	-	6	18	50	53	4	2	-	1	167
06	-	-	-	-	-	-	6	6	-	-	-	51	63
07	24	3	21	15	15	1	171	124	19	32	6	26	457
08	47	-	26	14	7	14	35	46	8	4	3	19	223
TOTAL	183	3	211	29	125	93	785	333	66	88	17	100	2,033

TABLE 3.2

Storage Tank Throughput for Responding Companies (1983)
(10^3 m^3)

COMPANY	B.C.	YUK.	ALTA.	NWT.	SASK.	MAN.	ONT.	QUE.	N.B.	N.S.	P.E.I.	NFLD	TOTAL
01	-	-	-	-	-	-	1,880.8	276.9	-	-	-	-	2,157.7
02	230.0	-	493.8	-	74.2	47.1	418.3	114.0	37.5	75.2	1.5	30.9	1,522.5
03	6.8	-	14.9	-	4.1	1.8	50.7	-	-	-	-	-	78.3
04	58.0	-	21.4	-	24.8	0.8	2,680.2	400.2	42.7	59.6	12.5	-	3,300.2
05	434.7	-	1,187.4	-	3.1	2,150.8	959.8	1,234.2	60.4	0.1	-	2.3	6,032.8
06	-	-	-	-	-	-	143.9	31.2	-	-	-	156.4	331.5
07	1,149.0	12.6	16.5	25.1	660.8	0.1	512.1	298.1	119.5	128.7	3.6	106.0	3,032.1
08	630.3	-	780.4	22.5	475.9	2,634.1	2,147.0	83.5	91.7	161.7	70.5	263.8	7,361.4
TOTAL	2,508.8	12.6	2,514.4	47.6	1,242.9	4,834.7	8,792.8	2,438.1	351.8	425.3	88.1	559.4	23,816.5

TABLE 3.3

Gasoline Storage Emissions for Responding Companies (1983)
(metric ton/yr)

COMPANY	B.C.	YUK.	ALTA.	NWT.	SASK.	MAN.	ONT.	QUE.	N.B.	N.S.	P.E.I.	NFLD	TOTAL
01	-	-	-	-	-	-	32.5	3.3	-	-	-	-	35.8
02	164.2	-	84.8	-	54.2	37.0	241.6	40.4	18.0	40.2	1.1	30.1	711.6
03	5.3	-	7.7	-	1.0	0.3	76.2	-	-	-	-	-	90.5
04	33.4	-	11.4	-	7.6	0.5	99.7	298.4	7.9	14.0	9.4	-	482.3
05	214.3	-	11.2	-	0.8	16.9	720.8	1100.1	70.2	0.0	-	5.0	2139.3
06	-	-	-	-	-	-	114.3	49.9	-	-	-	154.5	318.7
07	272.5	6.4	8.3	12.6	118.8	0.1	168.2	70.7	82.9	199.0	2.8	82.9	1025.2
08	70.2	-	465.1	25.6	5.2	13.7	107.5	94.1	6.3	3.1	70.6	219.3	1080.7
TOTAL	759.9	6.4	588.5	38.2	187.6	68.5	1,560.8	1,656.9	185.3	256.3	83.9	491.8	5,884.1

TABLE 3.4

Loading and Transit Losses for Responding Companies (1983)
(metric ton/yr)

COMPANY	B.C.	YUK.	ALTA.	N.W.T.	SASK.	MAN.	ONT.	QUE.	N.B.	N.S.	P.E.I.	NFLD	TOTAL
01	-	-	-	-	-	-	1,471.4	187.9	-	-	-	-	1,659.3
02	153.4	-	311.8	-	47.3	30.2	313.2	77.4	27.9	58.5	1.1	22.8	1,043.6
03	5.5	-	12.3	-	3.8	2.2	35.6	-	-	-	-	-	59.4
04	41.0	-	13.6	-	15.8	0.5	2,097.1	271.7	31.8	46.3	9.5	-	2,527.3
05	485.3	-	750.0	-	1.5	868.0	749.3	839.5	45.0	0.1	-	1.7	3,740.4
06	-	-	-	-	-	-	104.3	22.4	-	-	-	115.5	242.2
07	698.6	5.8	17.7	13.7	421.7	0.1	396.1	204.0	89.1	88.9	2.5	78.3	2,014.5
08	814.9	-	773.3	12.8	303.9	724.8	1,784.8	48.0	68.8	131.0	57.1	300.8	5,020.2
TOTAL	2,198.7	5.8	1,878.7	26.5	794.0	1,625.8	6,949.8	1,650.9	262.6	324.8	70.2	519.1	16,306.9

Note: These losses include:

i) losses at the storage tank while gasoline is transferred in or out of the tank
ii) losses involved in loading and unloading the transfer vehicle
iii) losses in transit.

to the next storage point. The totals given in Tables 3.3 and 3.4 were calculated using the equations given in Section 2, and the data supplied by the responding oil companies.

Table 3.5 contains estimated provincial and national totals for storage and handling losses at marketing terminals and bulk plants. These totals were obtained by prorating the data of Tables 3.3 and 3.4, using the total throughput reported in Statistics Canada 57-003 and the total throughput of the responding companies as reported in Table 3.2. In other words, if the throughput for the province from the questionnaires was less than that reported by Statistics Canada, the calculated emissions were multiplied by:

$$\frac{\text{Statistics Canada throughput}}{\text{Questionnaire throughput}}$$

If the questionnaire throughput exceeded the Statistics Canada value, the emissions were not adjusted. This occurred only for Manitoba.

In determining the throughput from the questionnaires, the overlap between marketing terminals and bulk plants noted earlier was accounted for using the distribution percentages given by Nichols (1983). For example, the gasoline distribution charts given by Nichols (1983) indicate that for British Columbia 54.4% of refinery output goes through marketing terminals, and 25.9% goes through bulk plants, for a total of 80.3%. It has therefore been assumed that the throughput for British Columbia reported in Table 3.2 (i.e. $2{,}508.8 \times 10^3$ m^3) is 80.3% of the total output of the companies responding to the questionnaire. The estimated total throughput for responding companies for British Columbia is then $3{,}124.3 \times 10^3$ m^3 ($2{,}508.8 \times 10^3 \times 100/80.3$). It is this figure which is entered as questionnaire throughput in the expression given above, and which may be compared directly with published sales data. A comparison of questionnaire throughputs with total gasoline sales (by province) is given in Appendix I.

TABLE 3.5

Estimated Total Emissions for Marketing Terminals and Bulk Plants (1983) (metric ton/yr)

Province	Storage	Loading and Transit	Total
B.C.	841.6	2,435.2	3,276.8
YUK.	14.0	12.7	26.7
ALTA.	686.9	2,193.0	2,879.9
NWT	38.2	26.5	64.7
SASK.	227.8	964.3	1,192.1
MAN.	68.5	1,625.8	1,694.3
ONT.	1,678.1	7,472.2	9,150.3
QUE.	2,990.2	2,979.3	5,969.5
NB.	429.4	608.5	1,037.9
NS.	573.7	727.1	1,300.8
PEI.	160.0	133.8	293.8
NFLD.	534.8	564.5	1,099.3
CANADA	8,243.2	19,742.9	27,986.1

Note: The data reported in this table have been derived from the calculated emissions given in Tables 3.3 and 3.4 by adjusting for total 1983 gasoline sales as reported in Statistics Canada 57-003, and therefore represent total emissions for all Canadian installations.

3.2 Service Station Emissions

Delivery and receipt into storage and vehicle refuelling losses at service stations were calculated using the equations developed by Nichols (1983) and summarised in Section 2. Seven companies provided data relating to service stations. However, one of these companies divested itself of its eastern Canada operations during 1985, and was not able to supply data for the corresponding service stations. Throughputs obtained from the questionnaires compared with Statistics Canada data (see Appendix I for details), show that the overall data recovery was about 30%.

The emissions based on questionnaire responses are reported in Tables 3.6, 3.7 and 3.8 for regular leaded, regular unleaded and premium unleaded gasoline respectively. These data are the combined delivery and receipt into storage and vehicle refuelling emissions for the responding oil companies, which are given the same code numbers as were used in the previous section. Note that a distinction has been made between those areas where the company does not operate (represented by a dash) and those areas for which no response was obtained (denoted by "no data").

Estimated total emissions were calculated by prorating the emissions calculated for the responding oil companies on the basis of total gasoline sales reported by Statistics Canada. These estimates are given in Table 3.9. The proration assumes similar operational practices and hence similar emissions per throughput apply to all companies. The increased uncertainty that proration has in estimating hydrocarbon emissions cannot be quantified.

No data were available for gasoline distribution through commercial accounts. An estimate was therefore made for emissions from this sector by using the distribution figures given by Nichols (1983), which give commercial account throughput as a fraction of service station throughput. Commercial account emissions were assumed to amount to the same fraction of service station emissions. These estimates are reported in Table 3.10. Estimates of emisions resulting from spillage during vehicle refuelling are given in Table 3.11.

TABLE 3.6

Service Station Emissions: Gasoline Type: Regular Leaded
(metric ton/yr)

COMPANY	B.C.	YUK.	ALTA.	N/T.	SASK.	MAN.	ONT.	QUE.	N.B.	N.S.	P.E.I.	NFLD	TOTAL
01	-	-	-	-	-	-	624.8	221.1	-	-	-	-	845.9
02	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	-
03	68.8	1.4	100.5	-	31.8	33.2	43.6	-	-	-	-	-	279.3
04	242.2	-	151.3	-	54.3	37.1	1,023.2	No Data	No Data	No Data	No Data	No Data	1,508.1
05	265.9	-	178.0	-	75.8	120.3	518.4	296.5	143.1	91.3	24.1	-	1,713.4
06	-	-	-	-	-	-	232.5	-	-	-	-	157.3	389.8
07	218.3	1.1	272.9	2.3	137.5	145.1	No Data	No Data	No Data	No Data	No Data	No Data	777.2
08	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	-
09	95.5	-	99.5	-	28.3	28.7	4.1	-	-	-	-	-	256.1
TOTAL	890.7	2.5	802.2	2.3	327.7	364.4	2,446.6	517.6	143.1	91.3	24.1	157.3	5,769.8

Note: Includes losses associated with delivery into underground storage tanks and vehicle refuelling.

TABLE 3.7

Service Station Emissions: Gasoline Type: Regular Unleaded
(metric ton/yr)

COMPANY	B.C.	YUK.	ALTA.	NWT.	SASK.	MAN.	ONT.	QUE.	N.B.	N.S.	P.E.I.	NFLD	TOTAL
01	-	-	-	-	-	-	649.7	192.4	-	-	-	-	842.1
02	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	-
03	30.4	0.5	50.7	-	14.4	20.4	45.1	-	-	-	-	-	161.5
04	107.2	-	76.6	-	20.9	19.5	1,091.3	No Data	No Data	No Data	No Data	No Data	1,315.5
05	147.6	-	121.3	-	37.4	83.6	555.3	259.7	116.8	109.3	19.2	-	1,450.2
06	-	-	-	-	-	-	241.8	-	-	-	-	177.0	418.8
07	115.4	0.5	163.7	1.5	62.2	89.8	No Data	No Data	No Data	No Data	No Data	No Data	433.1
08	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	-
09	51.5	-	62.2	-	12.6	18.1	4.1	-	-	-	-	-	148.5
TOTAL	452.1	1.0	474.5	1.5	147.5	231.4	2,587.3	452.1	116.8	109.3	19.2	177.0	4,769.7

Note: Includes losses associated with delivery into underground storage tanks and vehicle refuelling.

TABLE 3.8

Service Station Emissions: Gasoline Type: Premium Unleaded
(metric ton/yr)

COMPANY	B.C.	YUK.	ALTA.	N/T.	SASK.	MAN.	ONT.	QUE.	N.B.	N.S.	P.E.I.	NFLD	TOTAL
01	-	-	-	-	-	-	139.1	91.6	-	-	-	-	230.7
02	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	-
03	5.9	0	7.4	-	1.1	0.8	3.5	-	-	-	-	-	18.7
04	22.0	-	12.1	-	2.5	1.7	231.2	No Data	No Data	No Data	No Data	No Data	269.5
05	35.7	-	20.0	-	5.4	9.0	109.2	106.5	17.3	22.0	3.7	-	328.8
06	-	-	-	-	-	-	51.8	-	-	-	-	20.9	72.7
07	28.6	0.2	30.7	0.1	9.8	10.1	No Data	No Data	No Data	No Data	No Data	No Data	79.5
08	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	-
09	9.9	-	8.9	-	0.1	0	0.7	-	-	-	-	-	19.6
TOTAL	102.1	0.2	79.1	0.1	18.9	21.6	535.5	198.1	17.3	22.0	3.7	20.9	1,019.5

Note: Includes losses associated with delivery into underground storage tanks and vehicle refuelling.

TABLE 3.9

Prorated Estimates of Total Canadian Service Station Emissions
(metric ton/yr)

TYPES OF GAS	B.C.	YUK.	ALTA.	NWT.	SASK.	MAN.	ONT.	QUE.	N.B.	N.S.	P.E.I.	NFLD	TOTAL
RL	2,570.3	16.7	2,158.4	21.8	913.8	751.6	6,946.6	3,727.7	591.1	578.5	104.4	326.7	18,707.6
RU	1,138.7	7.5	1,205.7	13.5	398.1	490.0	7,579.3	3,216.6	482.3	695.9	109.2	382.9	15,719.7
PU	373.5	0.9	213.7	0.7	38.1	41.1	1,831.7	1,175.5	71.5	175.5	22.2	42.9	3,987.3
TOTAL	4,082.5	25.1	3,577.8	36.0	1,350.0	1,282.7	16,357.6	8,119.8	1,144.9	1,449.9	235.8	752.5	38,414.6

Note: 1. Includes losses associated with delivery into underground storage tanks and vehicle refuelling.
2. RL = Regular leaded
RU = Regular unleaded
PU = Premium unleased

TABLE 3.10

Prorated Estimates of Total Canadian Commercial Account Emissions
(metric ton/yr)

TYPES OF GAS	B.C.	YUK.	ALTA.	N.W.T.	SASK.	MAN.	ONT.	QUE.	N.B.	N.S.	P.E.I.	NFLD	TOTAL
RL	843.1	5.5	1,193.7	12.0	582.1	430.7	2,049.2	1,133.3	221.1	180.5	30.4	88.6	6,770.2
RU	373.5	2.4	666.8	7.4	253.6	280.8	2,235.9	977.8	180.3	217.2	31.9	103.8	5,331.4
PU	122.5	0.3	118.2	0.4	24.3	23.5	540.3	357.4	26.7	54.7	6.5	11.6	1,286.4
TOTAL	1,339.1	8.2	1,978.7	19.8	860.0	735.0	4,825.4	2,468.5	428.1	452.4	68.8	204.0	13,388.0

Note: 1. Includes losses associated with delivery into underground storage tanks and vehicle refuelling.
2. RL = Regular leaded
RU = Regular unleaded
PU = Premium unleased

TABLE 3.11

Hydrocarbon Emissions Associated with Spillage During Vehicle Refuelling

Province	Emissions (tonnes)
B.C.	290.6
YUK.	2.9
ALTA.	292.5
NWT	3.1
SASK.	104.7
MAN.	100.0
ONT.	910.7
QUE.	518.4
NB.	68.1
NS.	82.0
PEI.	12.0
NFLD.	41.7
CANADA	2,426.7

3.3 Benzene Emissions

Benzene is present as a component of gasoline, unless specifically removed. It is therefore also potentially present whenever gasoline vapour is emitted to the atmosphere. The method of calculating benzene emissions was summarised in Section 2.

Only two companies provided information regarding the benzene content of their product. An estimated range of total benzene emissions was therefore prepared assuming that benzene is 1 to 3 % of gasoline by weight, and using the throughputs and temperatures found in this study. These estimates are given in Table 3.12. The losses are given by province and are broken down into storage, loading and transit losses at marketing terminals and bulk plants, service station losses due to delivery and receipt into storage and refuelling at major oil companies and at commercial outlets, and losses due to spillage during refuelling at service stations.

3.4 Discussion

Total hydrocarbon emissions resulting from the marketing of gasoline are summarised in Table 3.13. A comparison of the emissions calculated in this work, with the most recent values available from EPS (for 1980) is presented in Table 3.14. Gasoline sales in 1980 were substantially higher than in 1983 (3.61×10^{10} ℓ as opposed to 2.89×10^{10} ℓ). A further column is therefore included in Table 3.14, in which the EPS emissions are multiplied by the ratio of 1983 sales to 1980 sales, to permit a more direct comparison. The overall agreement obtained (82 ktonne in this work, versus 93 ktonne for the EPS emissions) may be considered to be very good.

On a provincial basis, most losses occurred in Ontario (38%), followed by Quebec (21%), Alberta (11%) and British Columbia (11%). Within the distribution system, the majority (63%) of emissions occurred at

TABLE 3.12

Estimated Benzene Emissions (1983)
(metric ton/yr)

Province	Storage	Loading and Transit	Service Station	Total
B.C.	1.35 - 4.05	13.23 - 39.69	34.30 - 102.90	48.88 - 146.64
YUK.	0.01 - 0.03	0.08 - 0.24	0.35 - 1.05	0.44 - 1.32
ALTA.	0.52 - 1.56	6.40 - 19.20	14.19 - 42.57	21.11 - 63.33
NWT	0.02 - 0.06	0.07 - 0.21	0.15 - 0.45	0.24 - 0.72
SASK.	0.15 - 0.45	2.94 - 8.82	5.22 - 15.66	8.31 - 24.93
MAN.	0.07 - 0.21	7.00 - 21.00	5.35 - 16.05	12.42 - 37.26
ONT.	1.60 - 4.80	32.86 - 98.58	66.98 - 200.94	101.44 - 304.32
QUE.	1.59 - 4.77	8.23 - 24.69	35.13 - 105.39	44.95 - 134.85
NB.	0.41 - 1.23	2.73 - 8.19	7.30 - 21.90	10.44 - 31.32
NS.	0.47 - 1.41	2.95 - 8.85	9.51 - 28.53	12.93 - 38.79
PEI.	0.17 - 0.51	0.64 - 1.92	1.35 - 4.05	2.16 - 6.48
NFLD.	0.93 - 2.79	3.63 - 10.89	4.44 - 13.32	9.00 - 27.00
CANADA	7.29 -21.87	80.76 - 242.28	184.27 - 552.81	272.32 - 816.96

Note: The emission ranges correspond to a benzene content of gasoline in the range 1 to 3 %

TABLE 3.13

Total Hydrocarbon Emissions for Gasoline Marketing (metric ton/yr)

Province	Emissions
B.C.	8,989
YUK.	63
ALTA.	8,729
NWT	124
SASK.	3,507
MAN.	3,812
ONT.	31,244
QUE.	17,076
NB.	2,679
NS.	3,285
PEI.	610
NFLD.	2,098
CANADA	82,216

TABLE 3.14

Comparison of Emission Estimates with Values Supplied by EPS

Source	1983 Emissions This Work	1980 Emissions EPS (1986)	1983 Emissions Adjusted EPS (1986)a
Marketing and Bulk tanks	27,986	27,100	21,680
Filling of underground tanks plus vehicle refuelling	51,803	81,200	64,960
Underground tank losses	0	4,500	3,600
Spillage	2,427	3,000	2,400
Subtotal	82,216	115,800	92,640
Refinery	16,751	27,800	22,240
Total	98,967	143,600	114,880

Notes: a) EPS (1986) values multiplied by 0.80 to account for the difference in gasoline sales between 1980 (2.89×10^{10} ℓ) and 1983 (3.61×10^{10} ℓ). Sales data from Statistics Canada 57-003

service stations during delivery and receipt into storage and refuelling operations. Emissions during loading and transit from bulk plants and marketing terminals accounted for 24% of the total emissions.

Comparisons between the present (1983) estimates for service station emissions with those by Nichols (1983) for 1978 are given in Table 3.15. Included in Table 3.15 are data corresponding to the 1978 Nichols estimates prorated by the ratio of gasoline sales in 1983 to gasoline sales in 1978. The agreement between the 1978 emissions data obtained by Nichols and the 1983 emissions obtained in the present study is generally good (a discrepancy of less than 2% in the Canada wide total for example). When estimates based on the same year are compared, the discrepancies are of the order of 18% which is considered good also. It should be noted, however, that the data recovery rate was rather low for service stations, so that large adjustments were required in the estimation of total emissions. These large adjustments will introduce additional - but unquantifiable - uncertainties in the service station emissions estimates.

To place gasoline marketing emissions in context, they are compared in Table 3.16 with total VOC emissions as reported by EPS (1983). The comparison is presented for each province, and for Canada as a whole. The following should be noted regarding the data presented in Table 3.16:

1. Refinery storage emissions have been taken from PACE Report 85-1 (Grant, 1985)

2. The EPS data are for 1978, which is the most recent year for which data have been published. (Preliminary data for gasoline marketing emissions for 1980 were communicated for the purposes of this report (see Table 3.14), but provincial breakdowns were not available.) Comparisons derived using data from this study and EPS data in Table 3.16 refer to different years and should be used with some caution.

TABLE 3.15

Comparison of Service Station Emissions (metric ton/yr)

Province	This Work (1983)	Nichols (1978)*	Nichols (1983)++	Number of Outlets in 1983+
B.C.	4,082.5	4,362.2**	3,936.7	1,924**
YUK.	25.1	-	-	-
ALTA.	3,577.8	3,038.0***	2,829.9	1,606***
NWT	36.0	-	-	-
SASK.	1,350.0	1,196.6	1,075.7	1,322
MAN.	1,282.7	1,069.7	938.2	958
ONT.	16,357.6	15,783.4	13,579.1	5,497
QUE.	8,119.8	9,094.0	6,730.8	4,536
NB.	1,144.9	1,030.5	813.0	572
NS.	1,449.9	1,307.6	1,069.8	642
PEI.	235.8	207.5	163.9	120
NFLD.	752.5	690.0	558.5	435
CANADA	38,414.6	37,779.5	31,695.6	17,612

* Year for which the calculations were made
** Includes the Yukon
*** Includes the Northwestern Territories
\+ Average number from Ethyl Corp. (1983)
++ Obtained by multiplying Nichols 1978 estimate by the ratio of Statistics Canada gasoline sales in 1983 to sales in 1978

TABLE 3.16

Refinery, Gasoline Marketing Distribution Hydrocarbon Emissions and Other Hydrocarbon Emissions in Canada (tonne)

Province	Gasoline Distribution			Data Reported by EPS for 1978*					Gasoline Distribution %
	Refinery Storage**	This Work	Sub-total	Industrial Process	Fuel Combustion	Transportation	Miscellaneous	Total	
B.C.	2,014	8,989	11,003	82,722	2,467	107,893	95,663	288,745	3.8
YUK. ***	-	63	63						
ALTA.	1,973	8,729	10,702	182,702	48,053	113,207	46,766	390,728	2.7
NWT ***	-	124	124	47	804	4,013	24,088	28,952	0.7
SASK.	1,738	3,507	5,245	39,680	3,335	67,129	45,974	156,118	3.4
MAN.	-	3,812	3,812	9,903	2,388	49,741	20,510	82,542	4.6
ONT.	1,850	31,244	33,094	114,323	21,413	273,337	189,289	598,362	5.5
QUE.	6,079	17,076	23,155	96,705	30,422	169,279	131,470	427,876	5.4
NB.	304	2,679	2,983	4,445	3,384	21,846	15,655	45,330	6.6
NS.	2,793	3,285	6,078	32,304	4,204	26,279	16,231	79,018	7.7
PEI.	-	610	610	5	524	4,180	2,440	7,149	8.5
NFLD.	-	2,098	2,098	17,621	1,805	13,988	10,355	43,769	4.8
CANADA	16,751	82,216	98,967	580,457	118,799	850,892	598,441	2,148,589	4.6

* Most recent published data.
** Data from Grant (1985)
*** EPS data reported for Yukon and NWT combined.

3. The EPS estimates for gasoline marketing emissions (available from a breakdown of the miscellaneous category reported in Table 3.16), were substantially higher (234,450 tonne (EPS, 1983)) than was found in this work. The EPS methodology relied on the estimation of composite emission factors which were then multiplied by throughput (Vena, 1986). In contrast, the methodology used in this project was more detailed and calculated losses on individual tank types while accounting for differences in emission factors due to tank parameters and climatic factors.

4. The miscellaneous category includes:
   i) Gasoline and diesel marketing
   ii) Dry cleaning
   iii) Application of surface coatings
   iv) Structural fires
   v) General solvent use
   vi) Landfill sites
   vii) Forest fires
   viii) Slash burning
   ix) Incineration

   For most provinces (i) is the largest contributor (about 50%), with (iii) and (v) contributing much of the balance in the miscellaneous category. However, for Manitoba, Saskatchewan and B.C., the last 3 sectors predominate, while for Yukon and NWT, forest fires contribute 22,815 of the 24,088 tonnes in the miscellaneous category.

5. It is clear that the contribution of gasoline marketing to Canadian VOC emissions is relatively small and are of the order of 4% (note comparisons using different base years).

CONCLUSIONS

4 CONCLUSIONS

PACE has previously published surveys of emissions from refineries and from service stations. This is the first time that emissions have been compiled for the entire gasoline marketing chain.

The emissions were calculated using published equations and input data retrieved by questionnaires submitted to Canadian gasoline distributors. A very large amount of data was involved; individual calculations were carried out for each month of the year for more than 2,000 storage tanks at bulk plants and marketing terminals, and for about 30% of the more than 17,000 retail gasoline outlets in Canada.

Responses were received from the major oil comanies operating in Canada. Essentially complete data coverage was achieved for the calculation of storage losses at bulk plants and marketing terminals in British Columbia, Alberta, Saskatchewan, Manitoba, Ontario and Newfoundland, since the estimates for these provinces were within 15% of estimates based on independent Statistics Canada data (see Appendix Table A1.2). Similar estimates for the remaining provinces ranged from -57% to +57%. In the case of service station emissions, the response to questionnaires yielded a sample corresponding to an average of 30% of the throughput (range of 5% to 48% on a province-by-province basis). Hydrocarbon emissions were calculated explicitly from the questionnaire data from the responding companies. It was assumed that the questionnaire data were representative.

In both cases, the emissions calculated from questionnaire data were then scaled up in accordance with gasoline sales reported by Statistics Canada, to provide an estimate of total emissions associated with gasoline marketing in Canada.

It was estimated that total hydrocarbon emissions associated with gasoline marketing and refining in Canada totalled 98,967 tonnes in 1983. This figure is in good agreement with the estimate of 114,880 tonnes also for 1983 but based on 80% of the 1980 emissions estimated by EPS. (There was a 20% decline in gasoline sales between 1980 and 1983). The total hydrocarbon emissions in the marketing and distribution system correspond to 0.4% of the total throughput gasoline sales assuming an average density of 670 kg m^{-3} for gasoline (US EPA 1981). The contribution of the gasoline marketing and distribution hydrocarbon emissions to the total anthropogenic VOC emissions in Canada is only 4%. Refinery losses represent less than 1%. These contributions to the VOC burden are therefore of lesser importance compared to other sources such as transportation and industrial sources. On a provincial basis, most hydrocarbon emissions occurred in Ontario (38%) followed by Quebec (21%). Within the gasoline marketing and distribution system, most losses (63%) occur at service stations, followed by loading and transit losses at bulk terminals and marketing plants (24%). The losses at service stations calculated in this work are in good agreement with those calculated by Nichols (1983) for 1978. To place the emissions estimates in context, it may be noted that US service station emissions amount to about 1 million tonnes annually, with other gasoline marketing losses (including storage losses at the refinery) contributing a further 1.1 million tonnes (National Emission Data System data).

The questionnaire data for the marketing terminals and bulk plants represents a data set that could form the basis of a computerised inventory database that could be used for any future updates for estimating hydrocarbon emissions or for other purposes (provide regional capacity, sales or marketing information, planned maintenance, etc.).

5 REFERENCES

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APPENDIX I

ASSUMPTIONS AND ESTIMATES OF UNCERTAINTY

AI ASSUMPTIONS AND ESTIMATES OF UNCERTAINTY

Estimates of uncertainty have been given (U.S. EPA, 1977) for three of the emission equations presented in Section 2. These are: for fixed roof storage emissions - 10%, floating roof storage emissions - 25%, and tank truck loading emissions - 30%. The uncertainties in the storage emissions can be reduced if account is taken of factors such as the nature of deck fittings, seal condition, etc. (Laverman, 1984).

In this work, however, the uncertainties will be slightly greater than those quoted above, because of the non-availability of some of the required data. The major data gaps, and the corresponding assumptions required to fill these gaps, are identified below.

AI.1 Marketing Terminals and Bulk Plants

Data were not available for a number of tank related factors which have been identified as bearing on the rate of hydrocarbon loss (US EPA, 1977; API, 1983). These factors are listed in Table AI.1, together with the conditions assumed in this study.

AI.2 Loading and Transit Losses

The data requirements for loading and transit losses are less extensive than for tank related losses. It was assumed that all tank cars and tank trucks were in normal dedicated service. In addition, Reid vapour pressure, distillation slope and vapour to liquid ratio were not available for the Yukon or the Northwest Territories. The corresponding data for British Columbia and Alberta respectively were therefore used.

TABLE AI.1

Tank Related Factors for Which Data Were Not Available

Factor	Assumed Condition
Colour	White
Internal conditions	Average*
Deck fittings	None
Seal type and condition	Average*

* A default condition is defined in the relevant publications for "average".

AI.3 Service Station Emissions

As in the case of loading and transit losses, it was assumed that the physical properties of gasoline for British Columbia and Alberta apply respectively to the Yukon and the Northwest Territories.

Simplifying assumptions were necessary in the calculation of service station emissions because of the large number of installations involved. Among the most important of these assumptions are the use of average tank sizes, average delivery size into the underground tank, and average vehicle refuelling amount.

AI.4 Overall Assumptions

It was assumed that ambient temperature and pressure, and underground temperature were uniform throughout a calculation zone. This is a good assumption, since the actual values used related to the major population centres, where the bulk of the gasoline is marketed.

The major assumptions affecting the accuracy of all calculations result from the incomplete collection of data. The degree of completeness may be assessed by comparing the provincial throughput determined from completed questionnaires with provincial gasoline sales reported by Statistics Canada. This comparison is given in Table AI.2 for bulk plants and marketing terminals, and in Table AI.3 for service stations. Note that the throughputs determined in this work have been adjusted for the percentages of gasoline passing through both bulk plants and marketing terminals as reported by Nichols (1983). They are thus directly comparable with the Statistics Canada data.

As can be seen in Table AI.2 essentially complete data recovery was achieved for British Columbia, Saskatchewan, Ontario, Newfoundlandand the two territories. The most serious shortfall occurred for Quebec. Examination of data in Table AI.2 and Table 3.9 allows calculation of service station emissions per 10^3 m^3 throughput. This yields values of

TABLE AI.2

Throughput Comparisons
(Bulk and Plants and Marketing Terminals)
(10^3 m^3)

Province	This Work	Statistics Canada	% deviation*
B.C.	3,124	3,460	9.7
YUK.	16	35	54.3
ALTA.	2,983	3,482	14.4
NWT	56	37	-51.3
SASK.	1,026	1,246	17.7
MAN.	4,048	1,191	**
ONT.	10,084	10,842	7.0
QUE	3,429	6,172	44.6
N.B.	350	811	56.8
N.S.	436	976	55.3
P.E.I.	75	143	47.6
NFLD	457	497	8.1
Canada	26,084	28,892	9.3

* Defined as $\left(\frac{\text{Statistics Canada - This Work}}{\text{Statistics Canada}}\right) \times 100$

** See text.

TABLE AI.3

Throughput Comparisons
(Service Stations)
(10^3 m^3)

Province	This Work	Statistics Canada	% Recovery*
B.C.	1,232	3,460	36
YUK	7	35	20
ALTA	1,345	3,482	39
N.W.T.	2	37	5
SASK	456	1,246	37
MAN	574	1,191	48
ONT	3,695	10,842	34
QUE	887	6,172	14
N.B.	196	811	24
N.S.	150	976	15
P.E.I.	29	143	20
NFLD.	235	497	47
CANADA	8,808	28,892	30

*Defined as $\left(\frac{\text{This Work}}{\text{Statistics Canada}}\right) \times 100$

1.51 and 1.32 tonnes/10^3 m^3 for Ontario and Quebec, respectively. There is only a 13% difference in the values for Quebec and Ontario that may be accounted for by differences in the distribution of tank size ranges (Appendix III) and the types of loading practised in these provinces. Such differences could result in different emission rates on a per 10^3 m^3 throughput basis. The data for Quebec, which appear low, are therefore reasonable. In spite of careful checking and receipt of further data from the companies involved, it has not been possible to resolve the discrepancy found for Manitoba.

As is shown in Table AI.3 the degree of data completeness was somewhat lower for the service station questionnaires, noting, however, that responding companies were allowed the option of providing data for only a fraction of their outlets.

In view of the assumptions discussed above it is believed that the uncertainty in the individual provincial emission totals reported in Section 3 is approximately 50%. However, the uncertainty in the Quebec totals is probably slightly higher, because of the lower data recovery.

In the case of the benzene calculations, only two companies reported the benzene content of their gasoline. The emissions calculations were therefore carried out for an assumed range of benzene content.

APPENDIX II
QUESTIONNAIRE SUBMITTED TO OIL COMPANIES

I MARKETING TERMINAL DATA

Please identify a contact person for your organization.

Company Name : _____

Contact Person : _____
Name Title

Address : _____
No. Street City

_____
Province Postal Code

Telephone : ( )

II MARKETING TERMINAL DATA (cont.)

A. Marketing Terminal Gasoline Tankage

Please supply the information requested for each tank in gasoline service and specify units where appropriate.
(see page I-3 for notes)

Company Name: _____
Terminal Address: _____
(City, Province)

Identification (Tank Number)	Product (1)	Type (2)	Dia.	Height or Length	Design Capacity	Through-put (3)	Paint Colour (4)		Annual Average Storage Temp.
							Roof	Shell	

NOTES:

1. G - Gasoline, indicating the grade of gasoline stored (aviation [not kerosene based jet fuel], unleaded, premium unleaded, regular leaded).

2. C - Cone roof, E - External floating roof, I - Internal floating roof, U - Underground, O - Other (please specify e.g. Horton dome).

3. Throughput for 1983 (please specify units). If unavailable, please give total marketing terminal throughput pro-rated to tank size.

4. Possible Paint Colours include: White (W), Aluminum (A), Grey (G), Green (L), Black (B) or Other (O).

I MARKETING TERMINAL DATA (cont.)

B. Marketing Terminal Transfer

Total physical throughput in 1983 : _____
(i.e. physical as opposed to administrative throughput-specify units).

1. Delivery to Marketing Terminal

Please supply the breakdown requested below may be percentages, or actual amounts of gasoline delivered to this marketing terminal.

Transport Method					
Ship or Barge A	Ship or Barge B	Truck	Rail	Pipeline	Other (specify)

Note: A - draft greater than 15 feet
B - draft less than 15 feet.

I MARKETING TERMINAL DATA (cont.)

2. Shipment from Marketing Terminal

Please supply the breakdown by immediate destination requested below (percentage or actual amounts) and the loading method used for gasoline

Destination (where known)	Transport Method		
	Truck (1)	Rail	Other(specify)
Bulk Plant			
Service Station and Commercial Users			
Other (specify), or unknown or undefined			
Loading Method (2)			

Notes: 1) Please give also the average delivery by truck.

2) Note whether splash loading or short drop tube (S), long drop tube (D), bottom loading (B), or tight top fill (T).

II BULK PLANT DATA

Please identify a contact person for your organization.

Company Name : _____

Contact Person: _____
Name Title

Address : _____
No. Street City

_____
Province Postal Code

Telephone : ( )

II BULK PLANT DATA (cont.)

A. Bulk Plant Gasoline Tankage

Please supply the information requested for each tank in gasoline service specify units where appropriate (see page I-3 for notes)

Company Name: _____

Bulk Plant Address: _____

(City, Province)

Identification (Tank Number)	Product (1)	Type (2)	Dia.	Height or Length	Design Capacity	Through-put (3)	Paint Colour (4)		Annual Average Storage Temp.
							Roof	Shell	

NOTES:

1. G - Gasoline, indicating the grade of gasoline stored (aviation [not kerosene based jet fuel], leaded, regular unleaded, premium unleaded).

2. C - Cone roof, E - External floating roof, I - Internal floating roof, U - Underground, O - Other (please specify (eg. Horton dome)).

3. Throughput for 1983 (please specify units). If unavailable, please give total bulk plant throughput prorated to tank size.

4. Possible Paint Colours include: White (W), Aluminum (A), Grey (G), Green (L), Black (B) or Other (O).

II BULK PLANT DATA (cont.)

B. Bulk Plant Transfer

Total physical throughput in 1983 : _____
(i.e. physical as opposed to administrative throughput-specify units)

1. Delivery to bulk plant

Please supply the breakdown requested below (may be percentages, or actual amounts) of gasoline delivered to this bulk plant.

Transport Method					
Ship or Barge A	Ship or Barge B	Truck	Rail	Pipeline	Other (specify)

Note: A - draft greater than 15 feet
B - draft less than 15 feet.

2. Shipment from Bulk Plant

Please supply the breakdown by immediate destination (where possible) requested below (percentage or actual amounts), together with data on loading method.

Destination (where known)	Transport Method		
	Truck (1)	Rail	Other(specify)
Bulk Plant			
Service Station and Commercial Users			
Other (specify), or unknown or undefined			
Loading Method (2)			

Notes: 1) Please give also the average delivery by truck.

2) Note whether splash loading or short drop tube (S), long drop tube (D), bottom loading (B), or tight top fill (T).

III REGIONAL SERVICE STATION AND COMMERCIAL ACCOUNT DATA

Company Name : _____

Contact Person : _____

Title: : _____

Address : _____
No. Street City

Province Postal Code

Telephone : ( ) _____

Region : _____
(if applicable)

NOTE: Only one copy of Section III is required to cover all regions, though two or more copies may be used if this is more convenient.

III REGIONAL SERVICE STATION AND COMMERCIAL ACCOUNT DATA (cont.)

A. Service Station Inventory

Please indicate in the following table the total number of service stations supplied by class and by region.

NUMBER OF STATIONS IN EACH CATEGORY

Category[2] (gallons[3] throughput per year) / Region[1]	< 240,000	240,000 > and < 600,000	600,000 < and < 1,000,000	>1,000,000
Yukon				
N.W.T				
BC I				
BC II				
Alberta I				
Alberta II				
Saskatchewan				
Manitoba				
Ontario I				
Ontario II				
Metro Toronto				
Quebec				
Metro Montreal				
New Brunswick				
Nova Scotia				
PEI				
Newfoundland				

NOTE: (1) Regions are defined on the accompany map (page III-5).
(2) This information may be based on a 20 % sample, representative of the region. If done, what sample size was used? _____
(3) For metric units the following units should be used: 1 million, 2.5 million, and 4.5 million.

For each service station category, please supply average statistics for 1983 for each region.
(If available, replace this sheet with computerized output of service station statistics).

Region _____

Total Throughput Category (gallons) (1) / Item	< 240,000	> 240,000 and < 600,000	> 600,000 and < 1,000,000	>1,000,000
Average No. of Tanks per Service Station For Each Gasoline Grade [2]				
Average Size of Tanks (gallons) [1]				
Average Contents at* Time of Delivery (gallons) [1,2]				
Average Delivery Volume (gallons) * [2]				
Average No. of Pump Nozzles per Outlet for Each Gasoline Grade [2]				

NOTE:

1. Total of all grades. For metric units the following units should be used: 1 million, 2.5 million and 4.5 million.

2. Please break down according to gasoline grade, using the designation
   RL - regular leaded
   RU - regular unleaded
   PU - premium unleaded

* Please supply your best estimate for these quantities

GASOLINE SALES BY REGION

Please complete a copy of this page for <u>each</u> region listed below** Region _____

Month / Fuel*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Premium												
Unleaded												
Leaded												

* Please indicate units.

** British Columbia I & II
Alberta I & II
Ontario I & II
Metro Toronto
Quebec
Metro Montreal
Alternatively, please indicate per-centage split between subdivision of the provinces indicated.